Assessing Soil Carbon Sequestration

…in the southeastern USA and beyond

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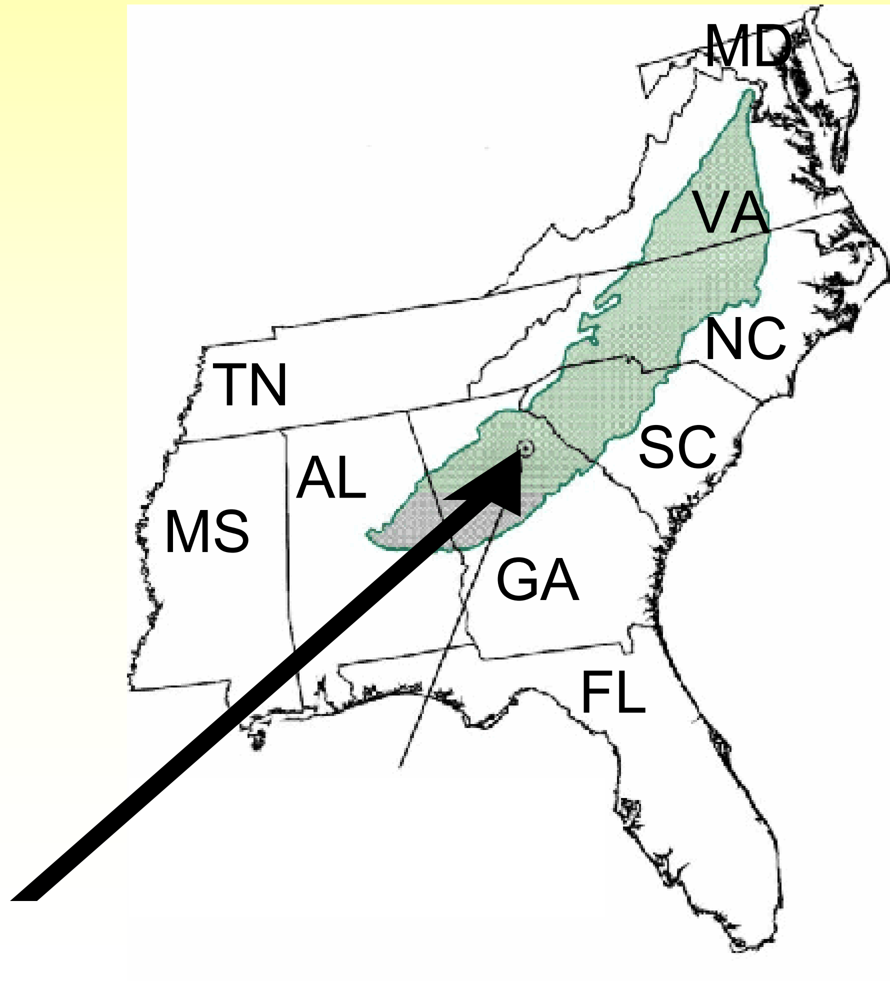
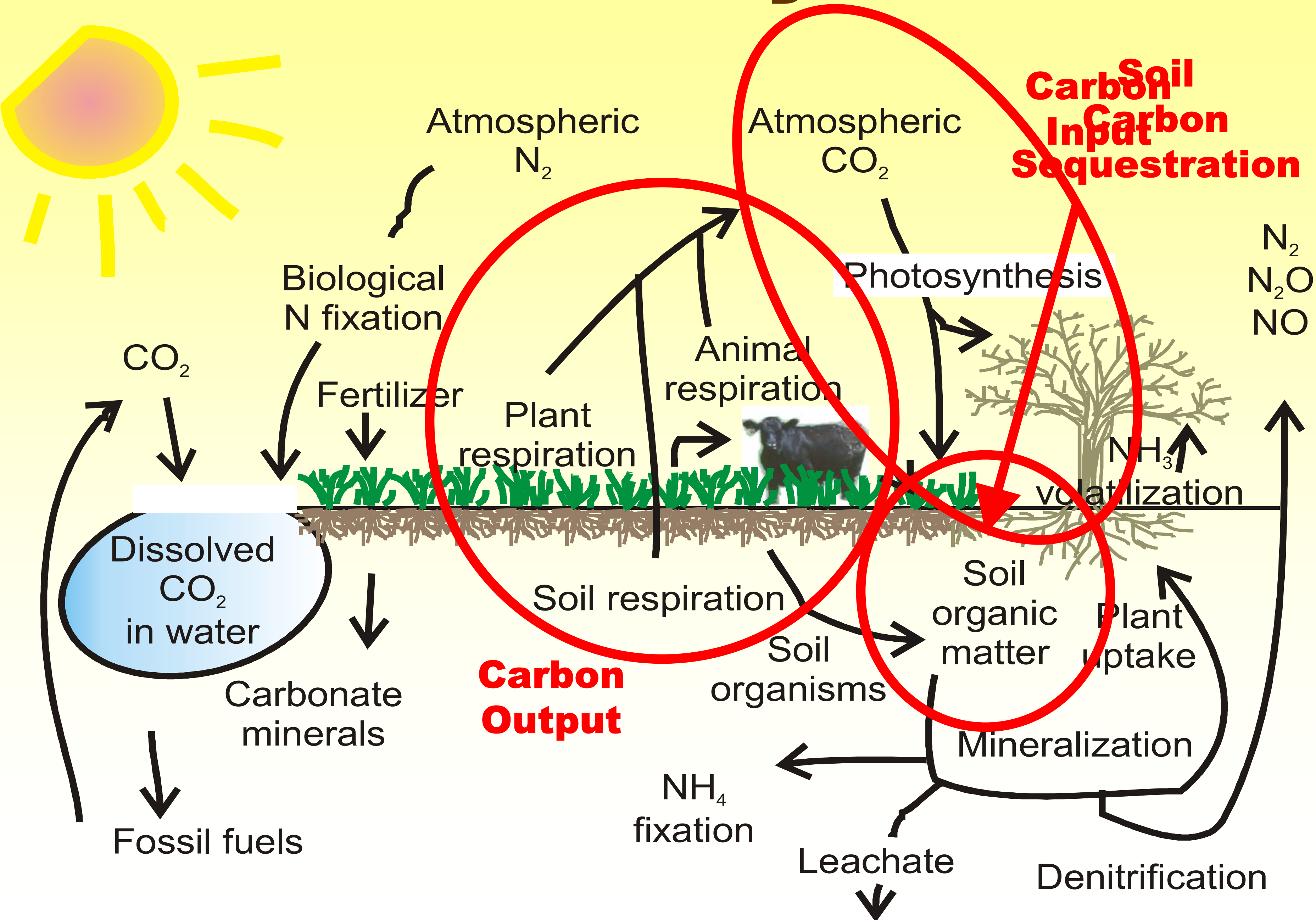
USDA ars

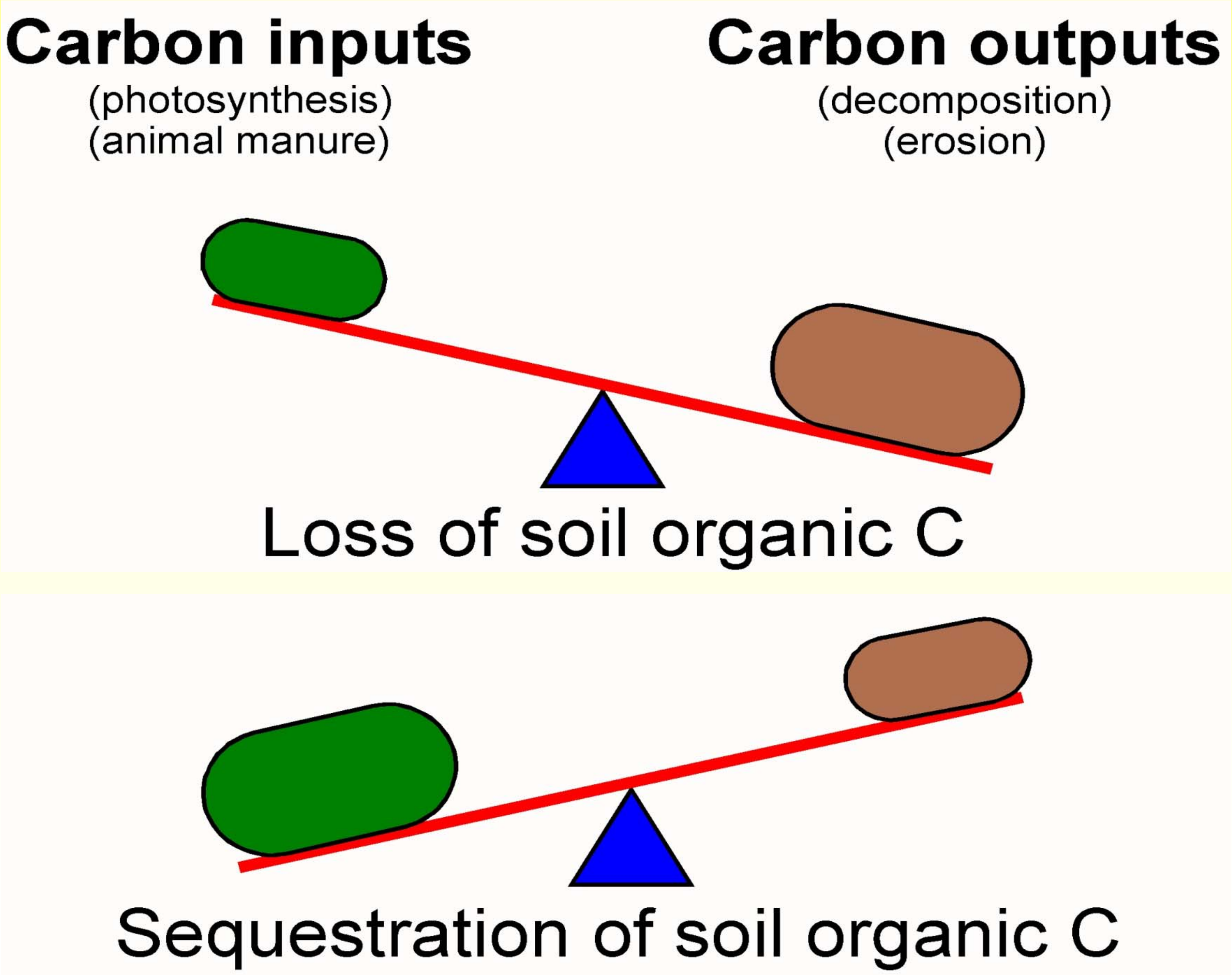
Watkinsville GA



Carbon Cycle



Carbon Cycle



Management Approaches

Focus on maximizing carbon input

ARS Image Number K5141-4

✓ **Plant selection**

- Species, cultivar, variety
- Growth habit (perennial / annual)
- Rotation sequence
- Biomass energy crops

✓ **Tillage**

- Type
- Frequency

✓ **Fertilization**

- Rate, timing, placement
- Organic amendments

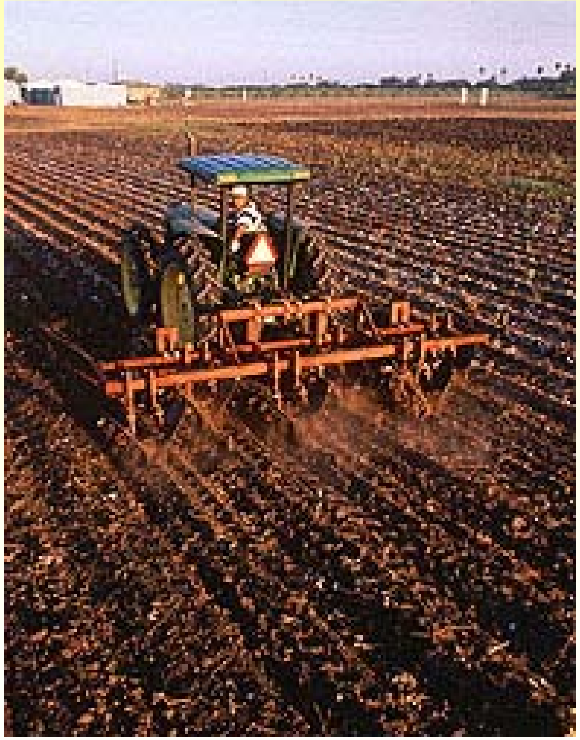
✓ **Integrated management**

- Pest control
- Crop / livestock systems

Management Approaches

Focus on minimizing carbon loss from soil

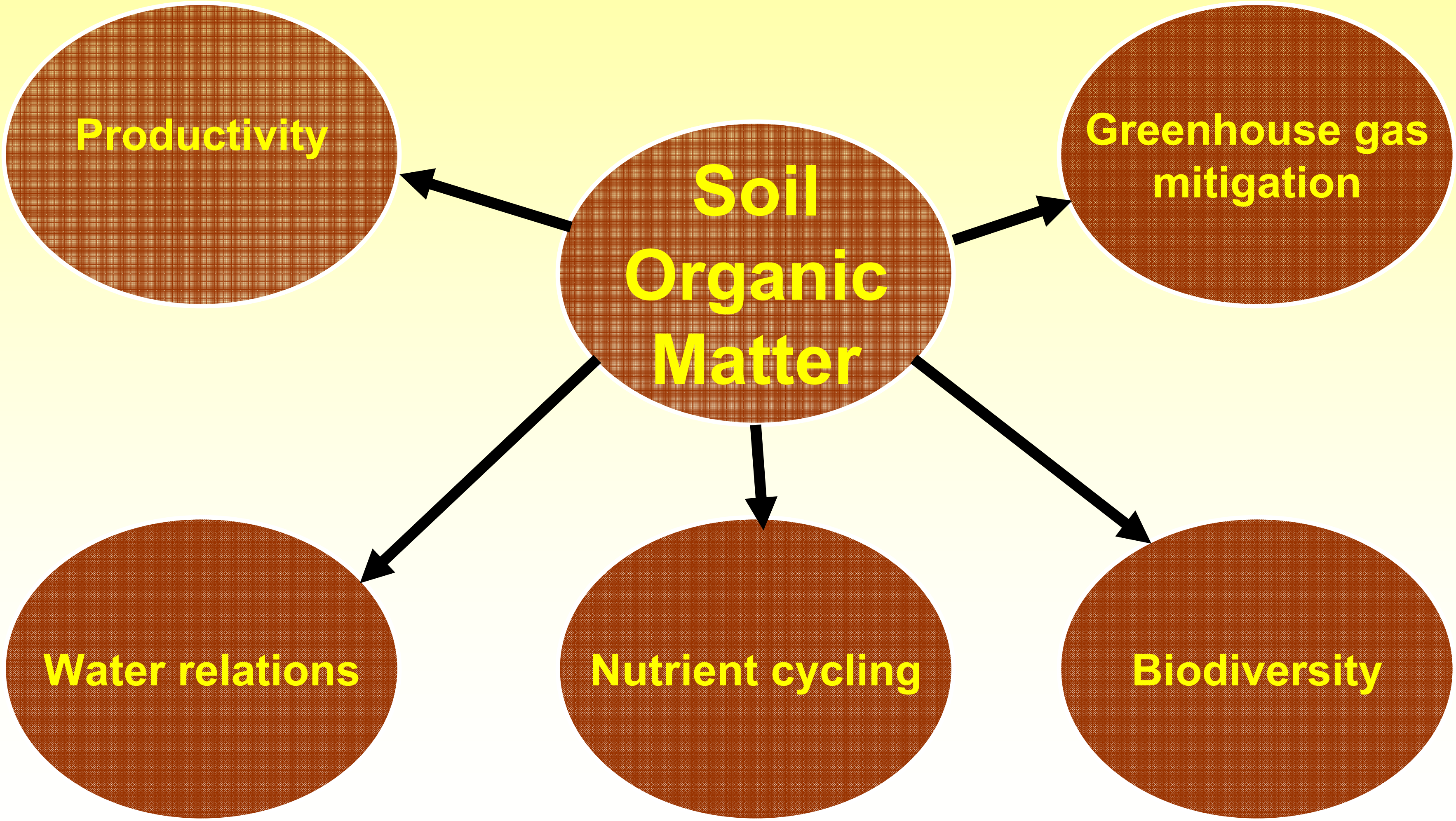
- ✓ **Reducing soil disturbance**
  - Less intensive tillage
  - Controlling erosion
- ✓ **Utilizing available soil water**
  - Promotes optimum plant growth
  - Reduces soil microbial activity
- ✓ **Maintaining surface residue cover**
  - Increased plant water use and production
  - More fungal dominance in soil



ARS Image Number K7520-2

Soil Organic Matter

Values and ecosystem services

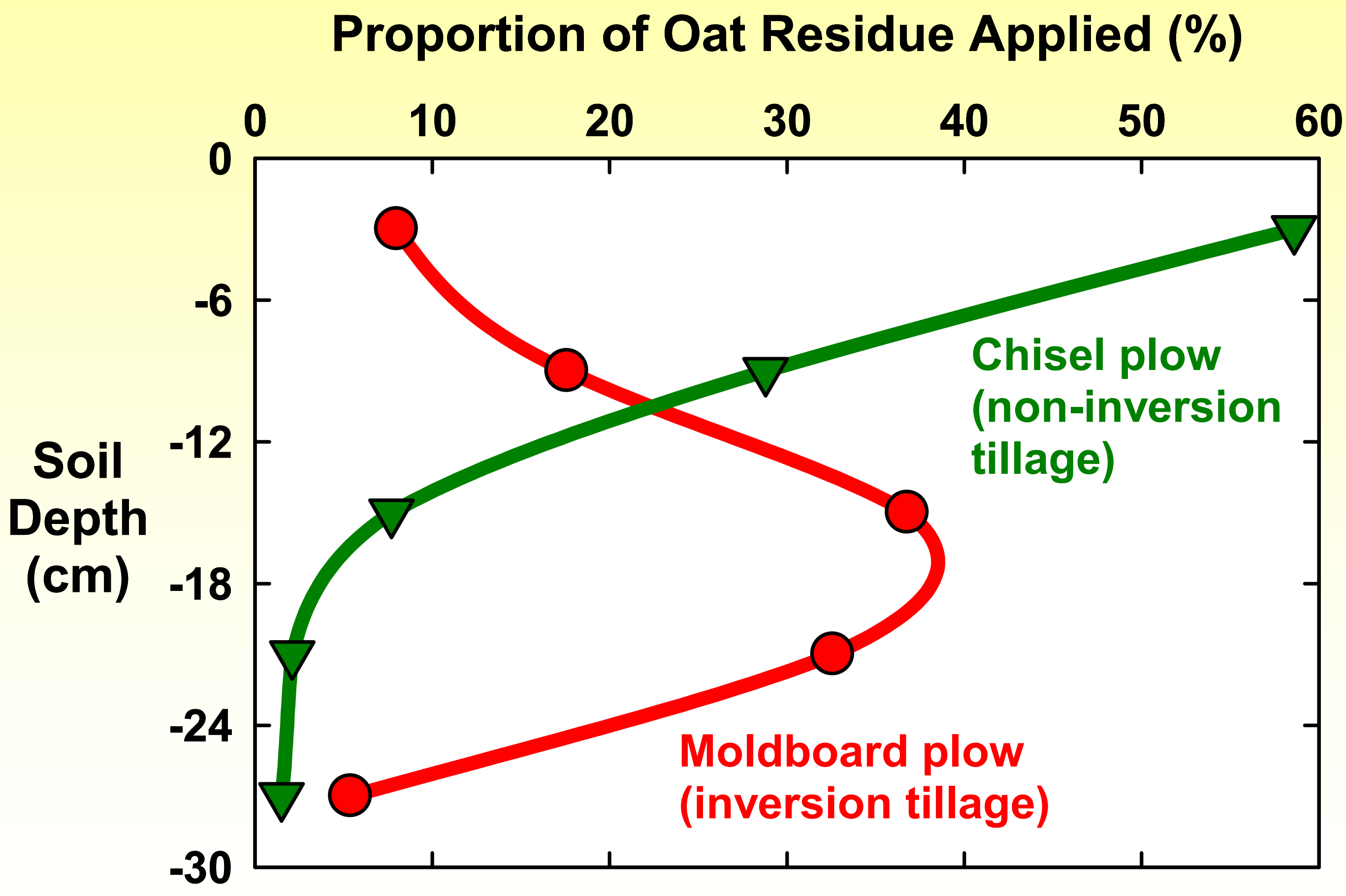


Soil Carbon Sequestration

- ✓ **Minimal disturbance of the soil surface is critical in avoiding soil organic matter loss from erosion and microbial decomposition**

Soil Carbon Sequestration

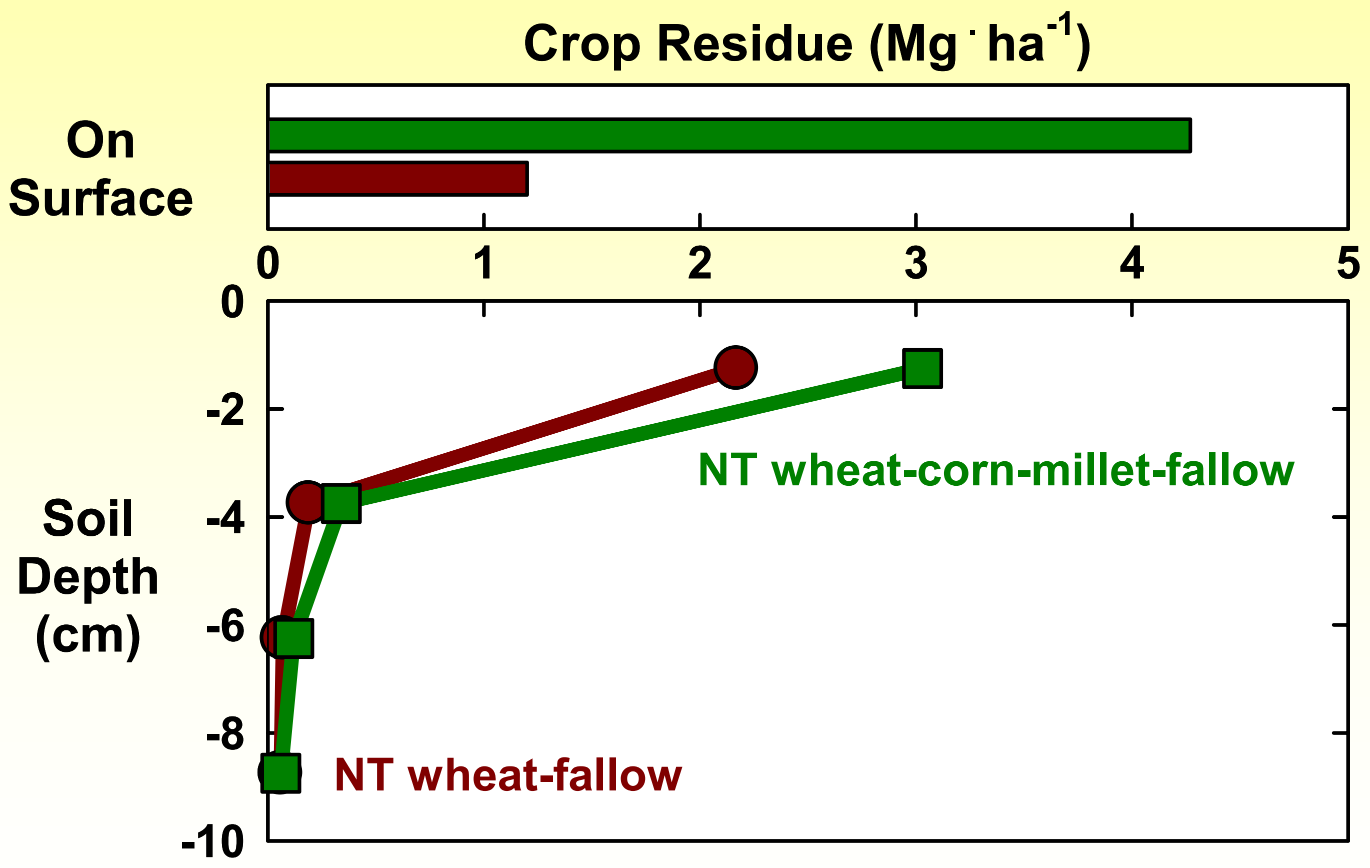
Tillage influence on depth distribution of crop residues



Data from Allmaras et al. (1996) Soil Sci. Soc. Am. J. 60:1209-1216

Soil Carbon Sequestration

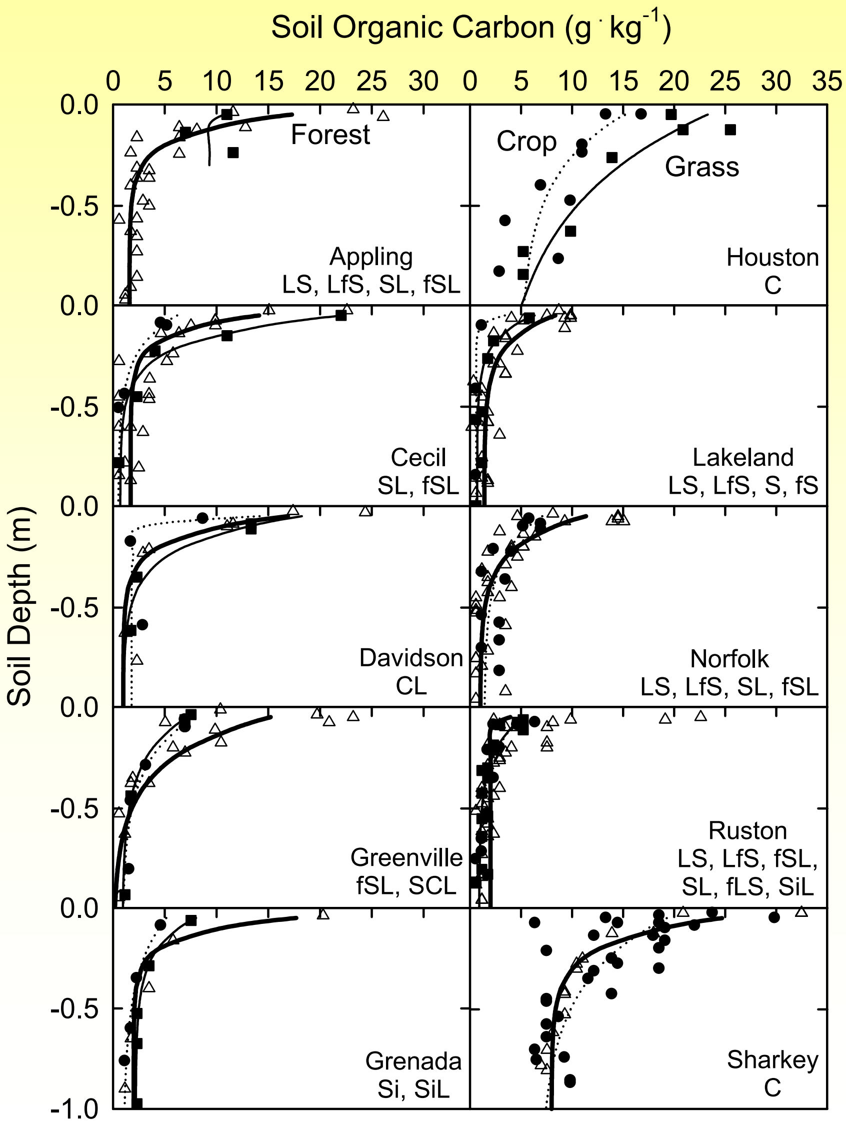
Depth distribution of crop residues without tillage



Data from Ortega et al. (2002) Agron. J. 94:944-954

Soil Carbon Sequestration

Soil-profile distribution of soil organic C

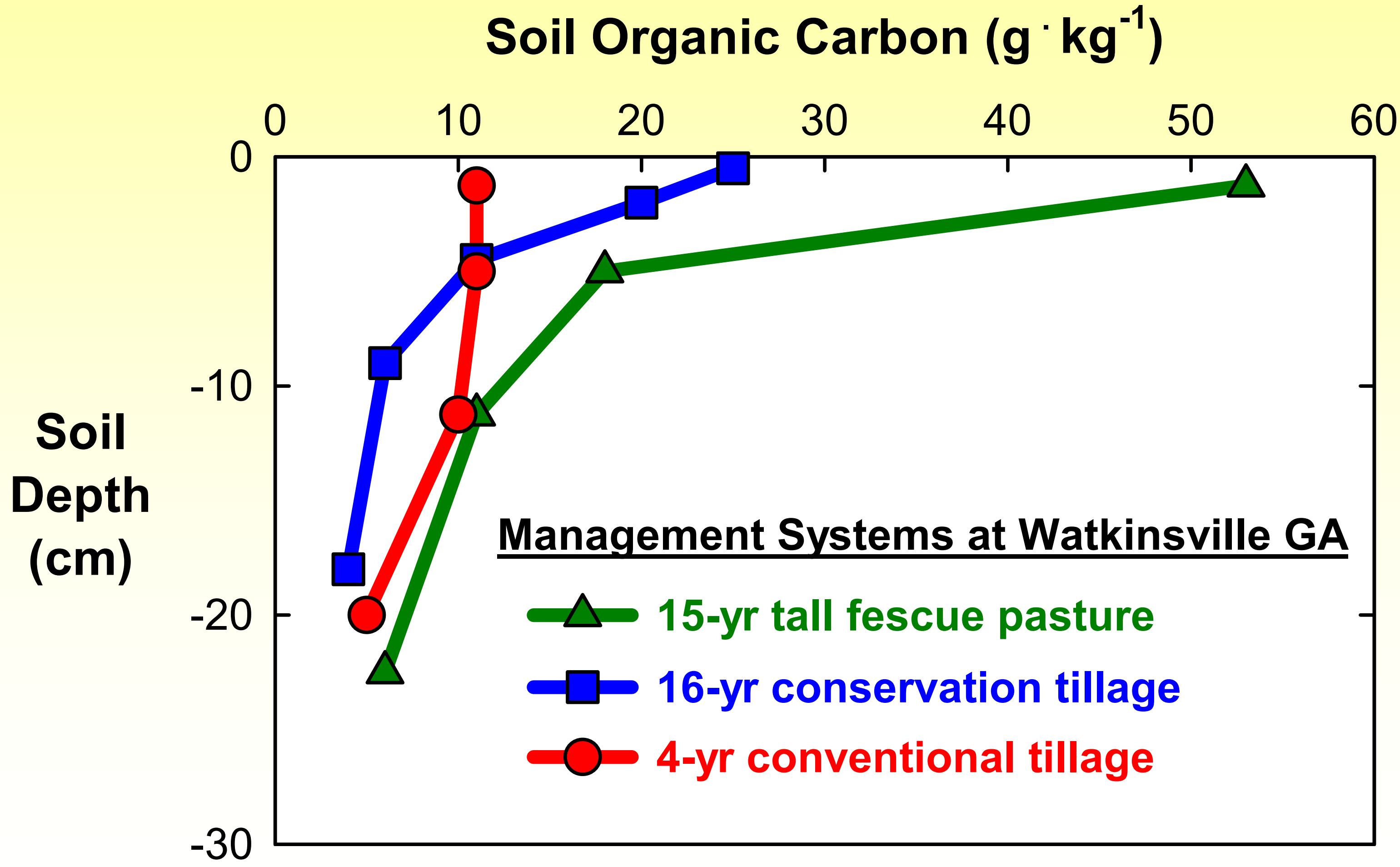


- ✓ The vast majority of soils in the southeastern USA and elsewhere have very low concentration of soil organic C below the surface 0.5 m
- ✓ Therefore there is a justified focus on measuring soil organic C in surface soil

From Franzluebbers (2005) Soil Till. Res. 83:120-147 with data from McCracken (1959)

Soil Carbon Sequestration

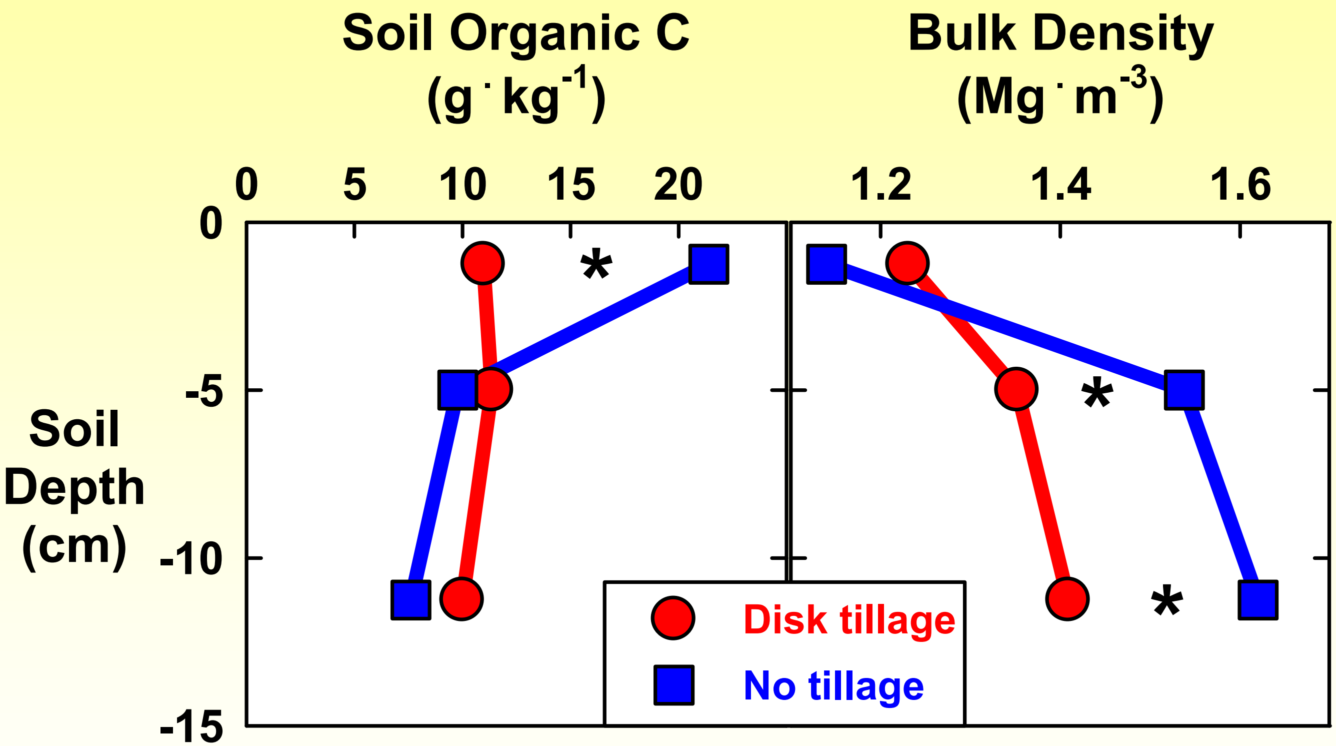
Depth distribution of soil organic C



From Schnabel et al. (2001) Ch. 12, Pot. U.S. Grazing Lands Sequester C, Lewis Publ.

Soil Carbon Sequestration

Depth distribution of soil organic C



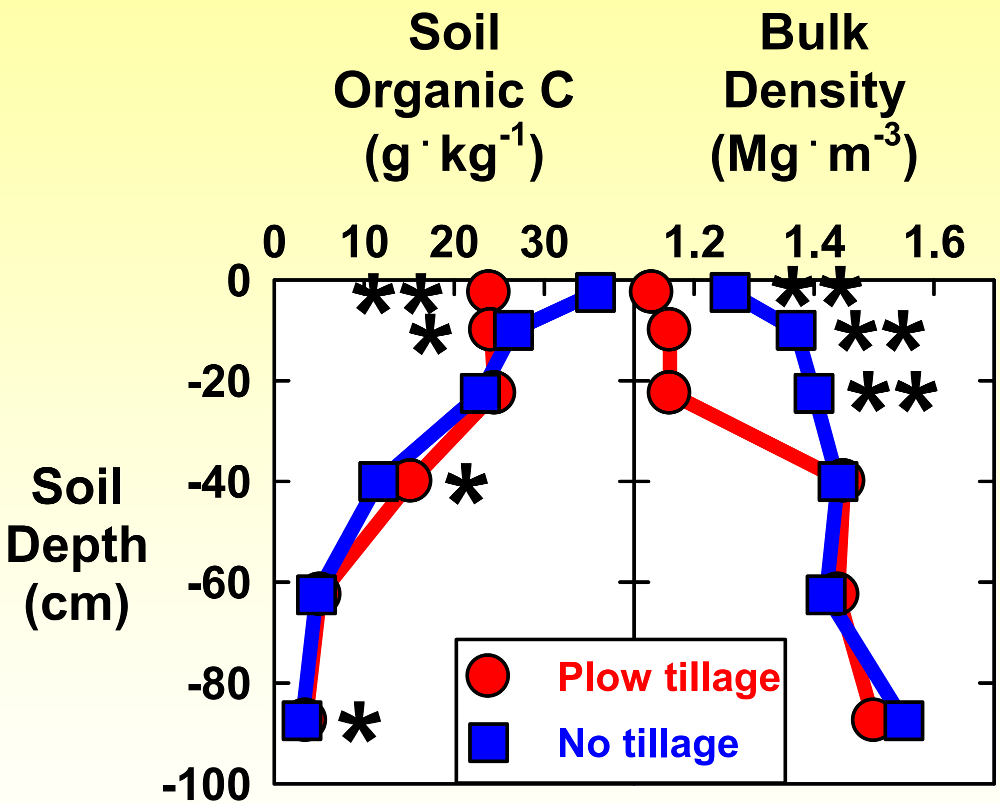
	Carbon Content (Mg · ha^{-1}) DT		NT
	0.1	*	4.3
	3.3	*	5.9
	7.5		7.4
	10.3		8.9
Soil (0-15 cm)	21.1		22.2
Soil + residue	21.2	*	26.5

Replicated experiment
Georgia – SCL
Typic Kanhapludult
4-yr study
Sorghum, soybean, cotton

Data from Franzluebbers et al. (1999)
Soil Sci. Soc. Am. J. 63:349-355

Soil Carbon Sequestration

Soil-profile distribution of soil organic C



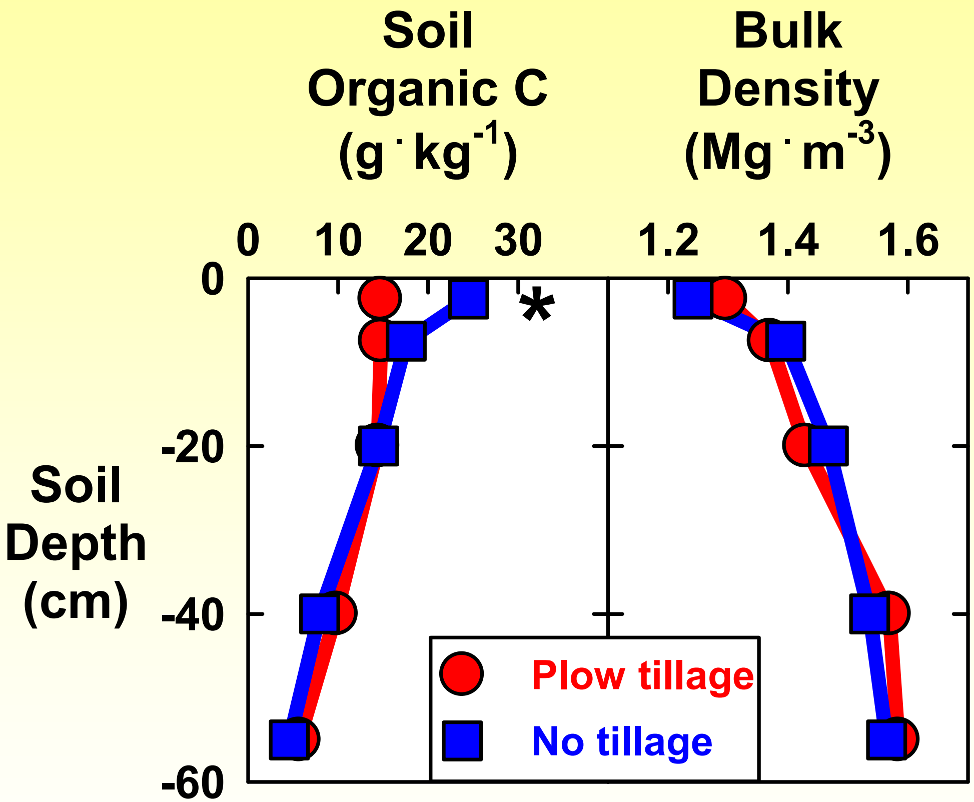
	Carbon Content ($Mg \cdot ha^{-1}$) PT		Carbon Content ($Mg \cdot ha^{-1}$) NT	Cumulative Carbon Sequestration Rate (Mg/ha/yr)
	13.6	<<	22.5	0.32
	27.9	<<	36.4	0.62
	42.8	<	48.2	0.81
	43.9	>	33.3	0.44
	18.2		16.7	0.38
	12.8		12.2	0.36
Soil (0-30 cm)	84.1	<	107.0	
Soil (0-100 cm)	159.2	<	169.3	

Replicated experiment
Indiana – SiCL
Typic Haplaquoll
28-yr study
Corn and corn/soybean

Data from Gal et al. (2007) Soil Till. Res. 96:42-51

Soil Carbon Sequestration

Soil-profile distribution of soil organic C



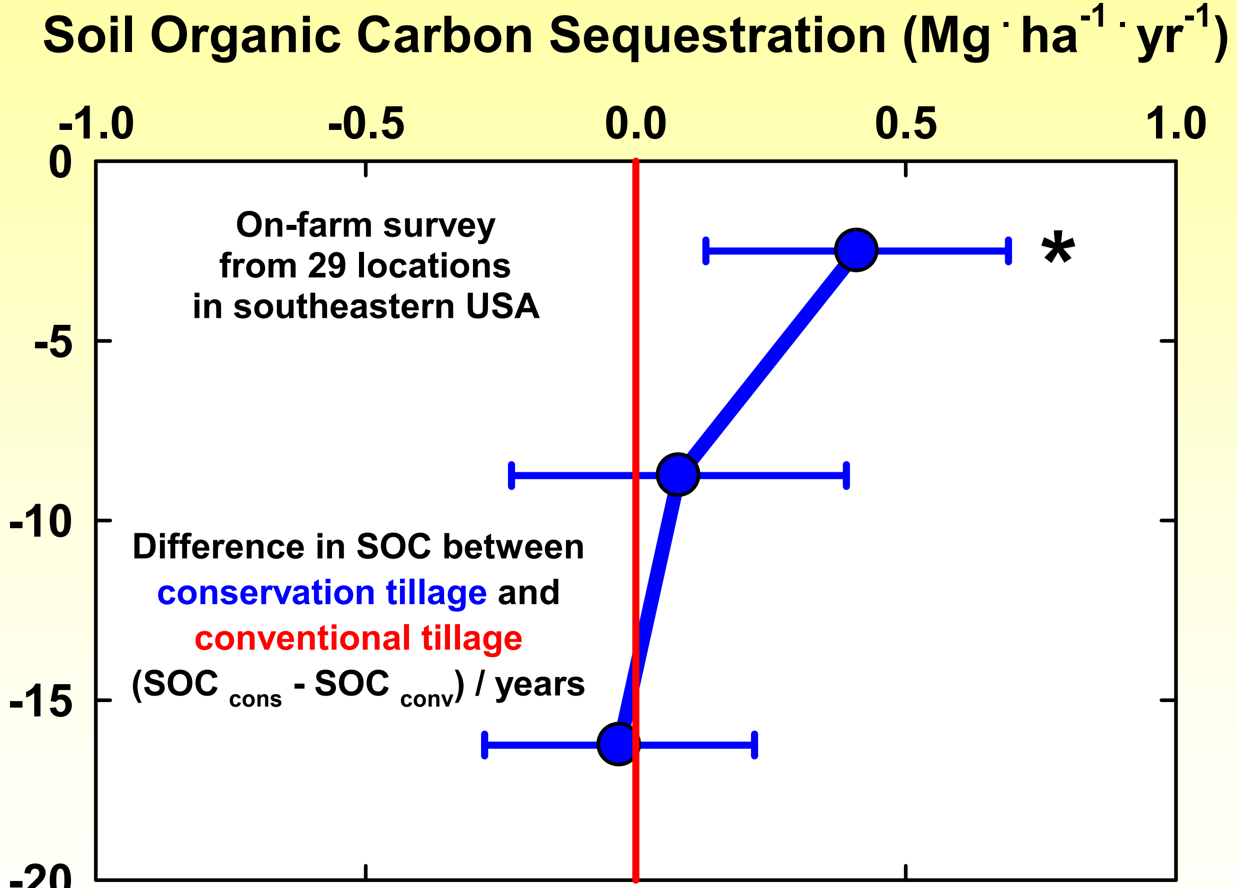
Depth	Carbon Content ($Mg \cdot ha^{-1}$) PT		Carbon Content ($Mg \cdot ha^{-1}$) NT	Cumulative Carbon Sequestration Rate (Mg/ha/yr)
	10.1		11.9	0.14
	9.5	<	15.0	0.56
	41.2		41.6	0.60
	30.7		24.2	0.09
	9.0		7.2	-0.05
Soil (0-10 cm)	19.7	<	27.0	
Soil (0-60 cm)	100.6		100.0	

Field survey – KY, OH, PA
11 different soils
Alfisols, Ultisols, Inceptisols
13 ± 7 years of tillage system
Corn, soybean, alfalfa, vegetables

Data from Blanco and Lal (2008)
Soil Sci. Soc. Am. J. 72:693-701

Soil Carbon Sequestration

Calculation by relative difference



Sequestration of SOC (Mg ha^{-1} yr^{-1})
0.41
0.08
-0.03

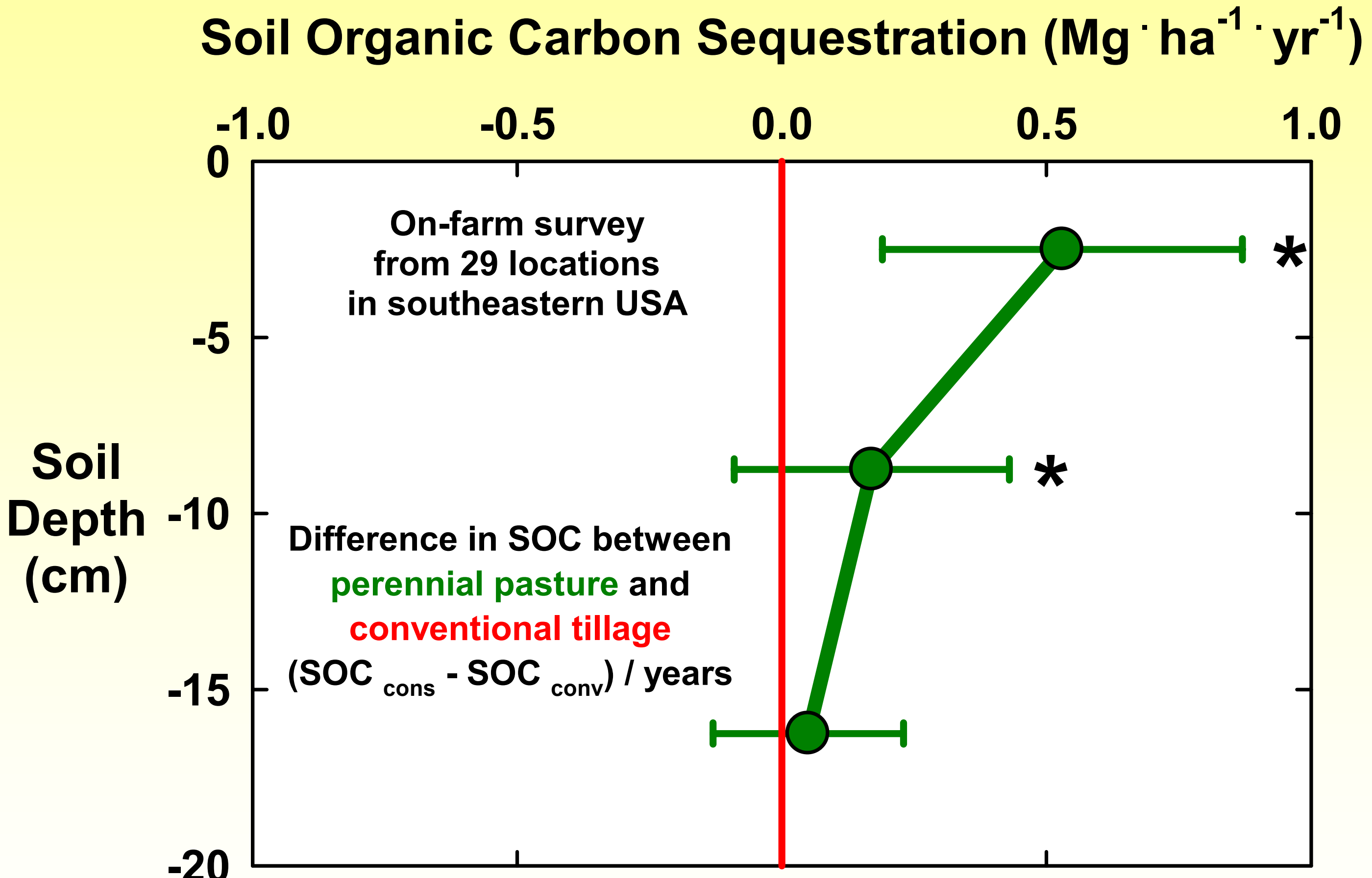
0-20 cm 0.45 *

Field survey – AL, GA, SC, NC, VA
Ultisols, Alfisols, Inceptisols
12 ± 6 years of conservation tillage
Cotton, corn, soybean, peanut

Data from Causarano et al. (2008)
Soil Sci. Soc. Am. J. 72:221-230

Soil Carbon Sequestration

Calculation by relative difference



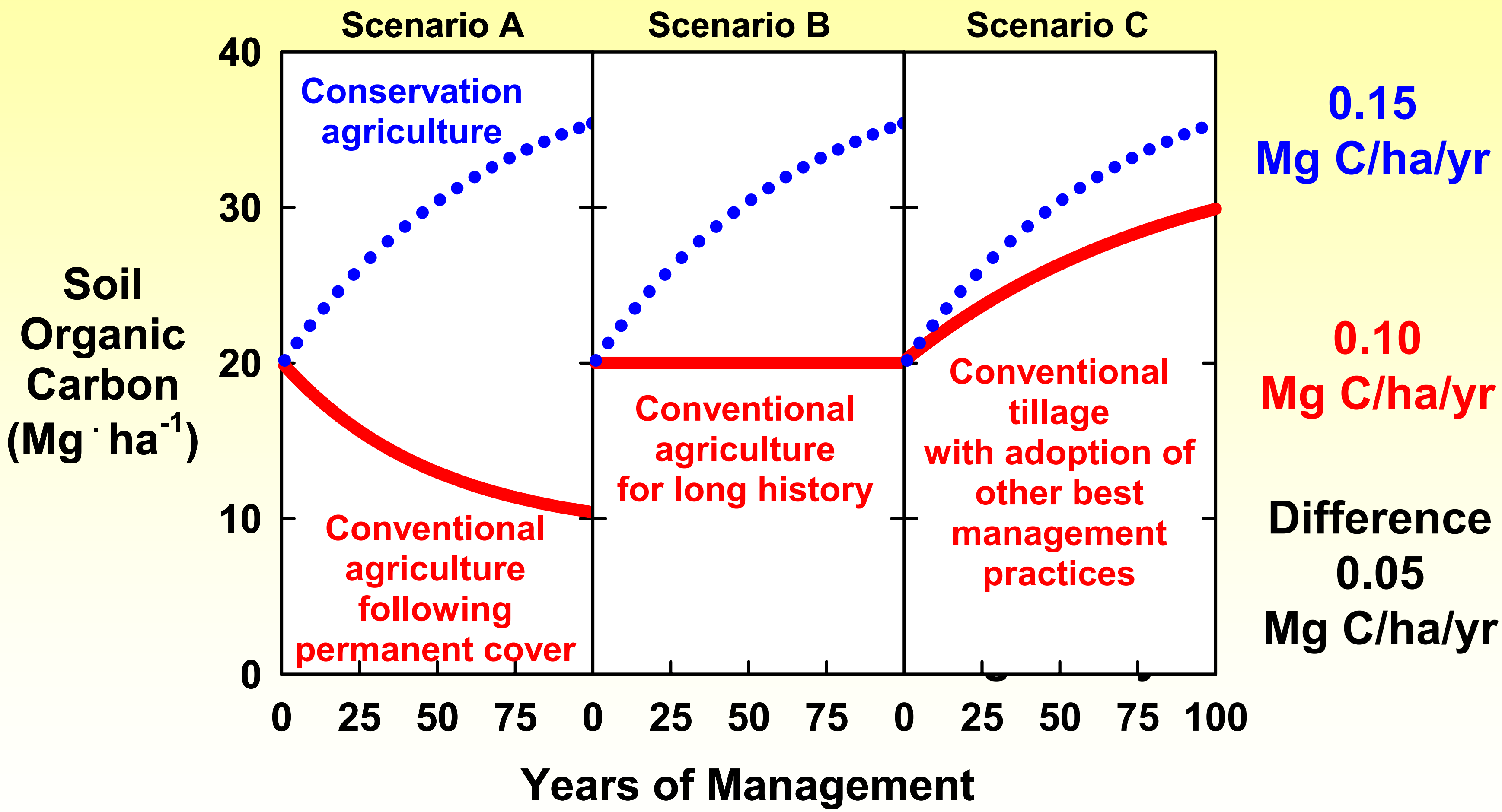
Sequestration of SOC ($Mg\ ha^{-1}\ yr^{-1}$)
0.53
0.17
0.05
0-20 cm 0.74 *

Field survey – AL, GA, SC, NC, VA
Ultisols, Alfisols, Inceptisols
12 ± 6 years of conservation tillage
Cotton, corn, soybean, peanut

Data from Causarano et al. (2008)
Soil Sci. Soc. Am. J. 72:221-230

Soil Carbon Sequestration

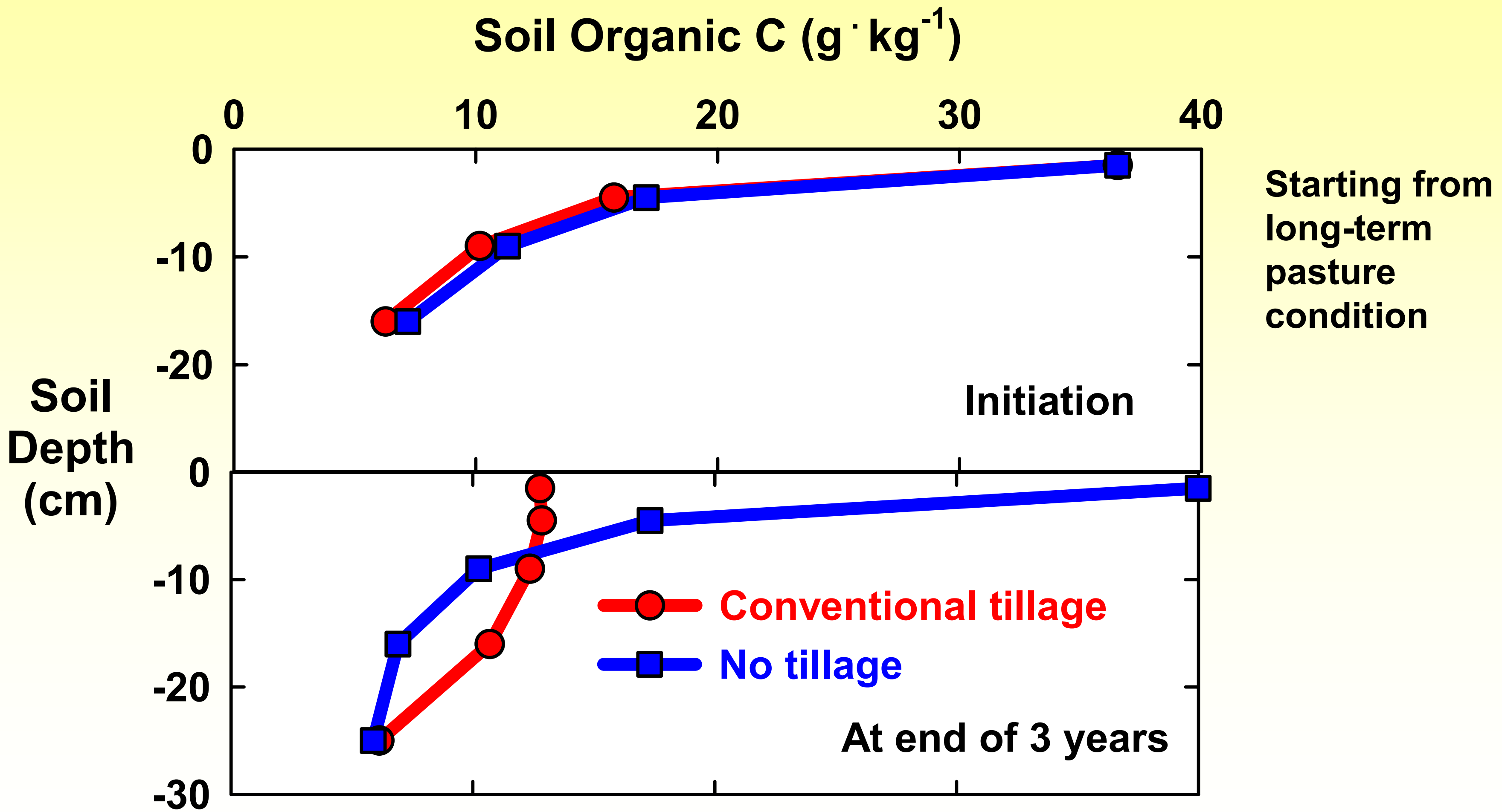
Calculation by change with time



Temporal and comparative approaches of value; in combination best!

Soil Carbon Sequestration

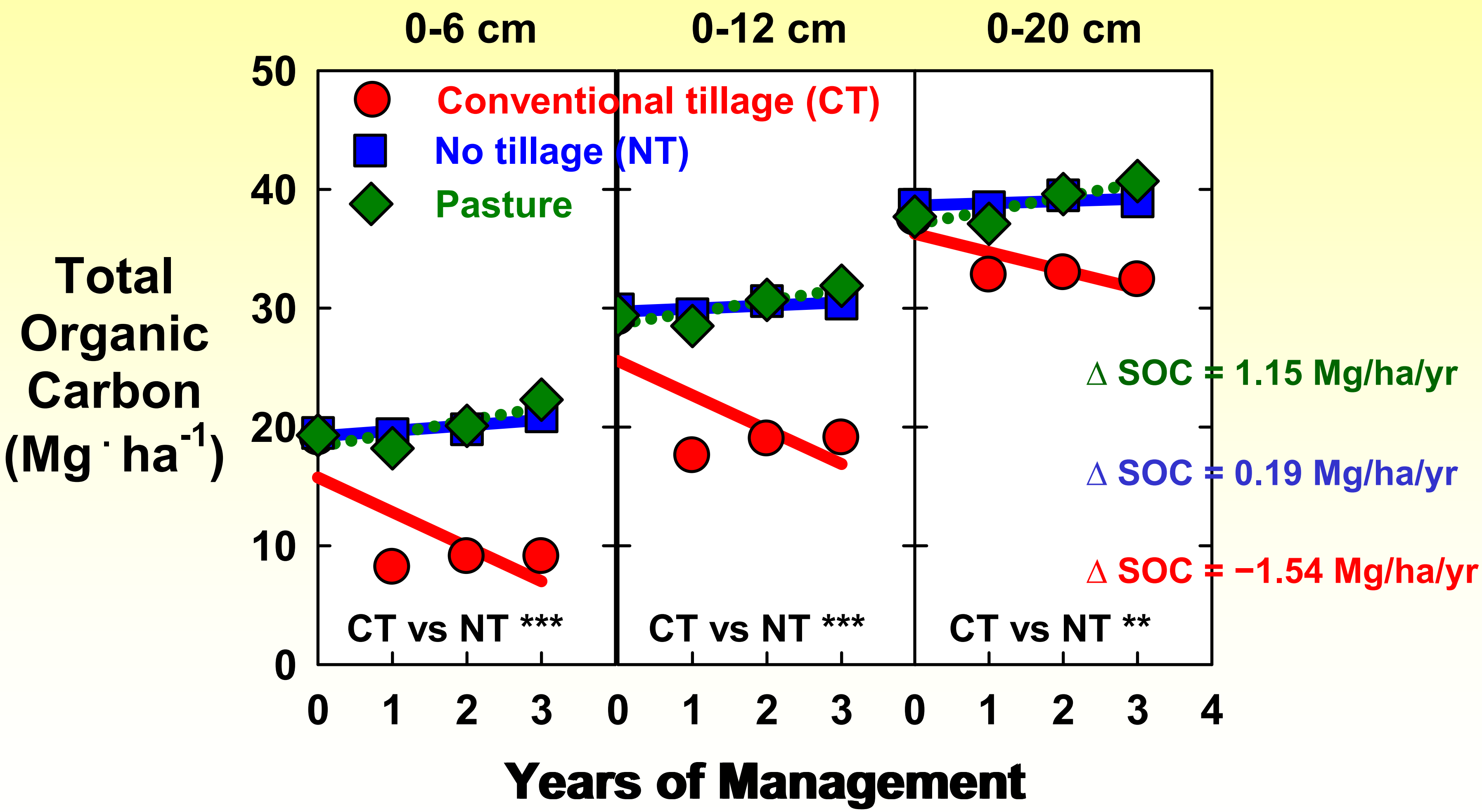
Example of short-term change



Franzluebbers and Stuedemann (2008) Soil Sci. Soc. Am. J. 72:613-625

Soil Carbon Sequestration

Example of temporal and comparative combination

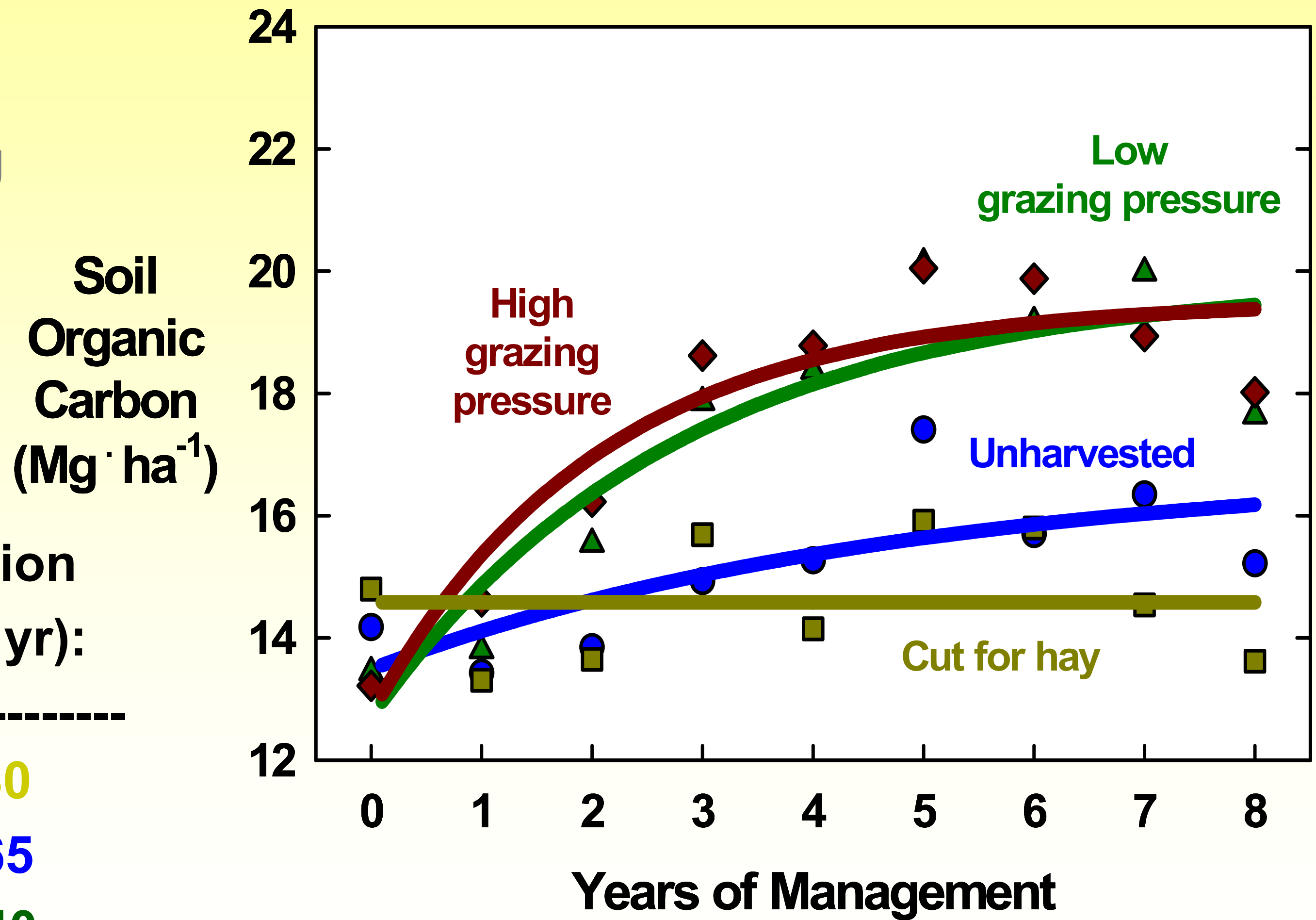


Franzluebbers and Stuedemann (2008) Soil Sci. Soc. Am. J. 72:613-625

Soil Carbon Sequestration

Example of temporal and comparative approaches

Establishment of bermudagrass pasture following long-term cropping in Georgia USA (16 °C, 1250 mm)



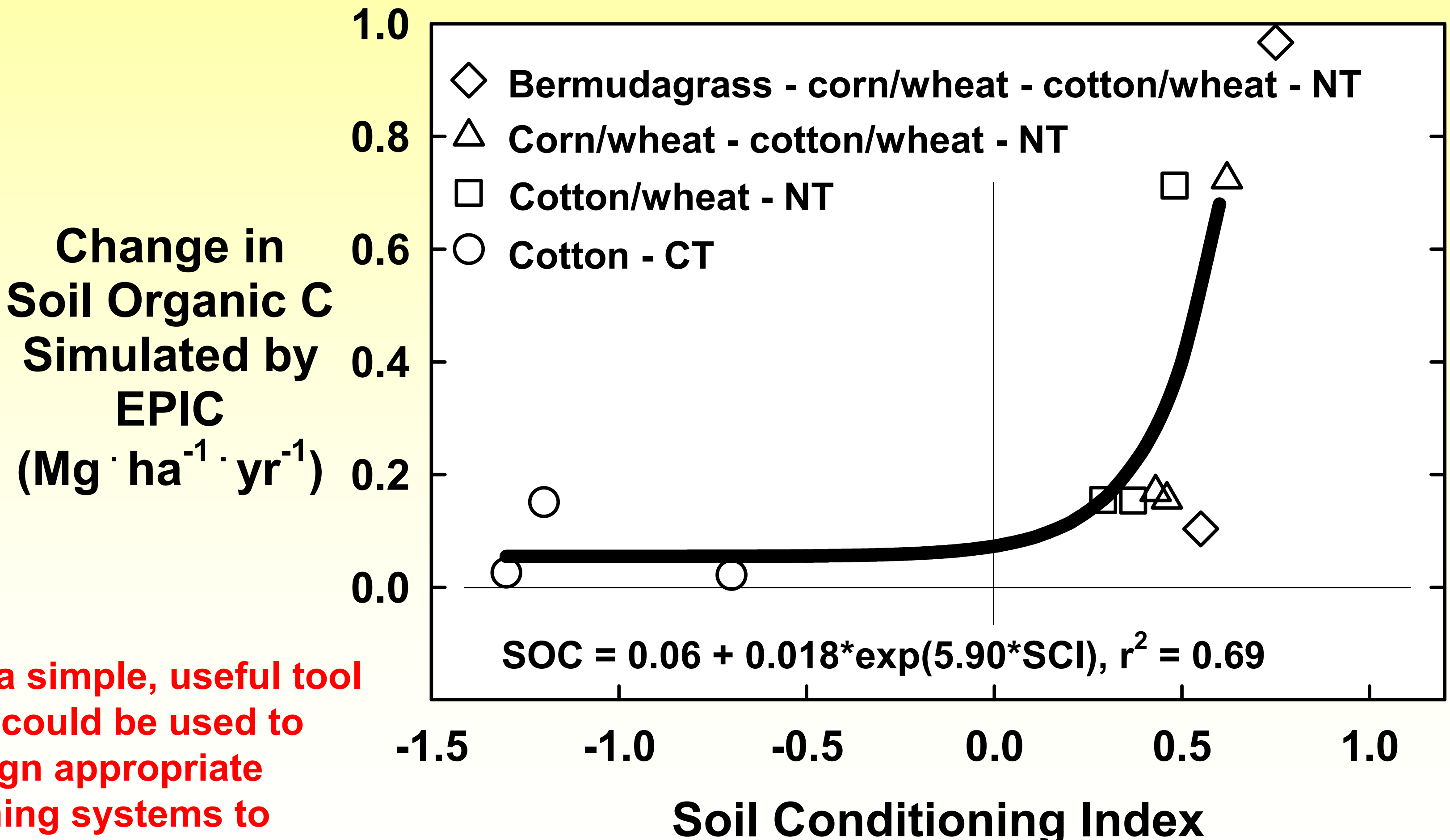
Soil C sequestration ($Mg\ ha^{-1}\ yr^{-1}$) (0-5 yr):

Hayed	0.30
Unharvested	0.65
Grazed	1.40

Franzluebbers et al. (2001) Soil Sci. Soc. Am. J. 65:834-841 and unpublished data

Soil Carbon Sequestration

Modeling of regional farming systems

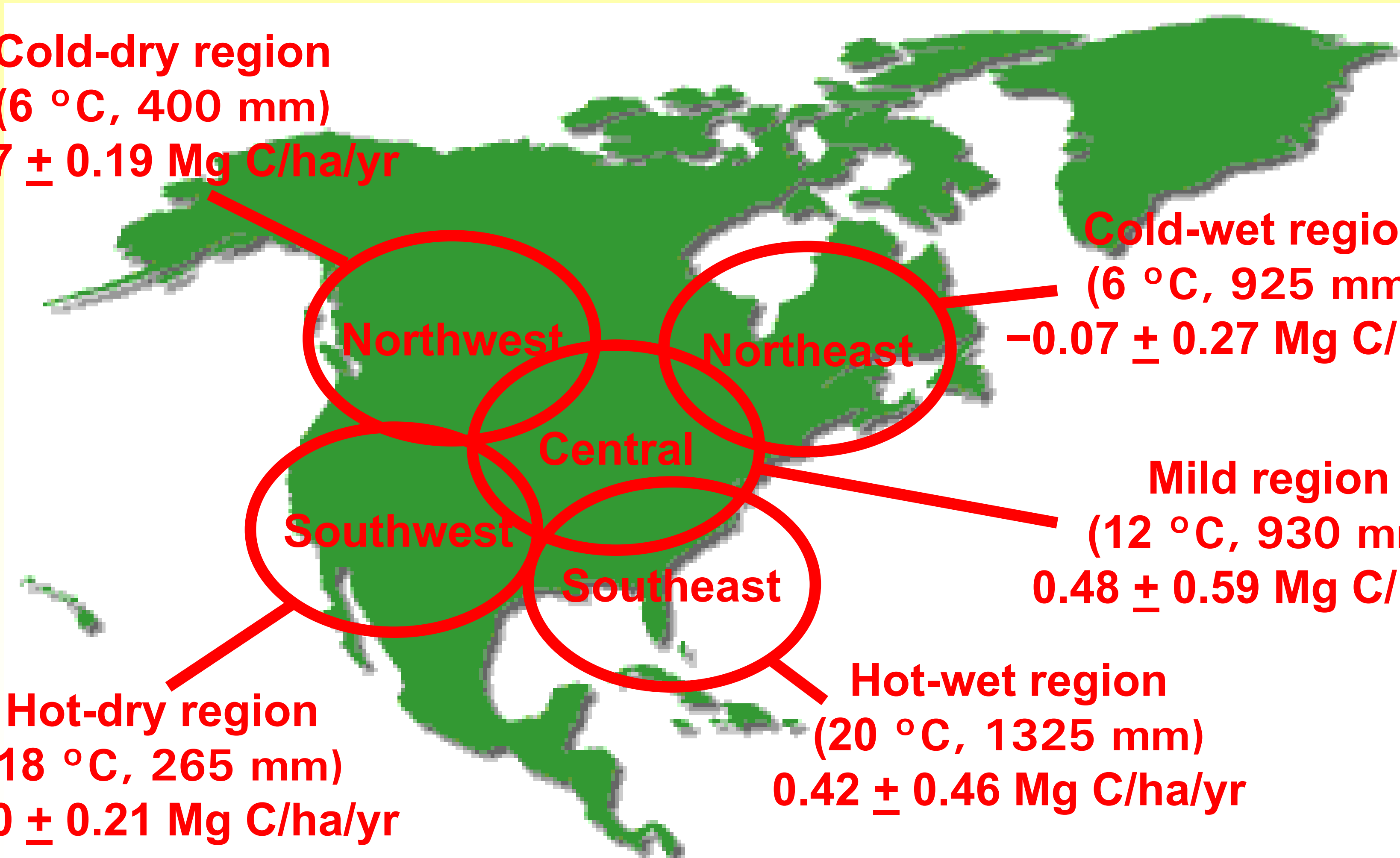


SCI a simple, useful tool that could be used to design appropriate farming systems to maximize C sequestration in Georgia

Abrahamson et al. (2007) J. Soil Water Conserv. 62:94-102

Soil Carbon Sequestration

In the USA and Canada, conservation-tillage cropping can sequester an average of 0.33 Mg C/ha/yr



Data from Franzluebbers and Follett (2005) Soil Tillage Res. 83:1-8

Soil Carbon Sequestration

- ✓ No tillage needs high-residue producing cropping system to be effective

Photos of 2 no-tillage systems in Virginia USA

Soil Organic Carbon Sequestration in the Southeastern USA

0.28 ± 0.44 Mg C/ha/yr
(without cover cropping)

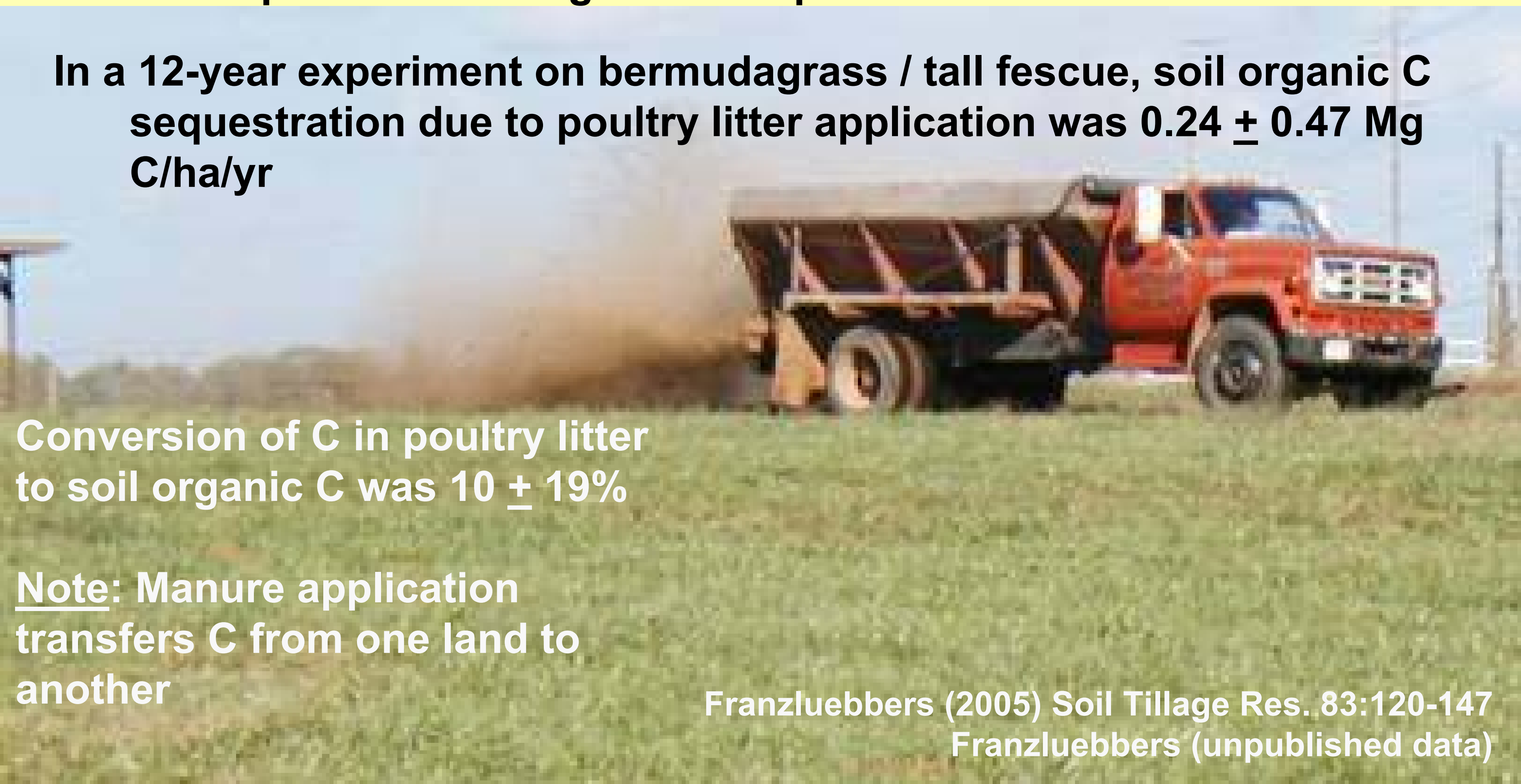
0.53 ± 0.45 Mg C/ha/yr
(with cover cropping)

Franzluebbers (2005) Soil Tillage Res. 83:120-147.

Soil Carbon Sequestration

Influence of animal manure application

Since animal manure contains 40-60% carbon, its application to land should promote soil organic C sequestration



In a 12-year experiment on bermudagrass / tall fescue, soil organic C sequestration due to poultry litter application was 0.24 $\pm$ 0.47 Mg C/ha/yr

Conversion of C in poultry litter to soil organic C was 10 $\pm$ 19%

<u>Note</u>: Manure application transfers C from one land to another

Franzluebbers (2005) Soil Tillage Res. 83:120-147
Franzluebbers (unpublished data)

Soil Carbon Sequestration

Influence of animal manure dependent on climate

Percentage of carbon applied as manure retained in soil
(review of literature in 2001)

Temperate or frigid regions (23 ± 15%)

Thermic regions (7 ± 5%)

Moist regions (8 ± 4%)

Dry regions (11 ± 14%)

Soil Carbon Sequestration

Integration of crops and livestock

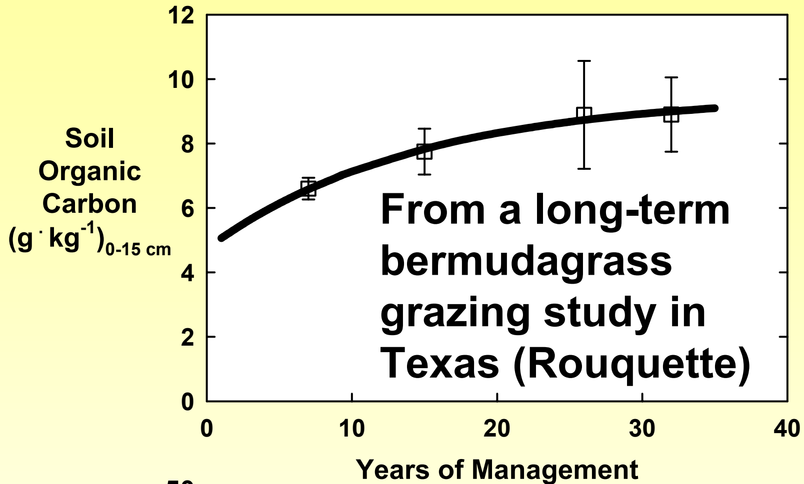
✓ **Opportunities exist to capture more carbon from crop and grazing systems when the two systems are integrated:**

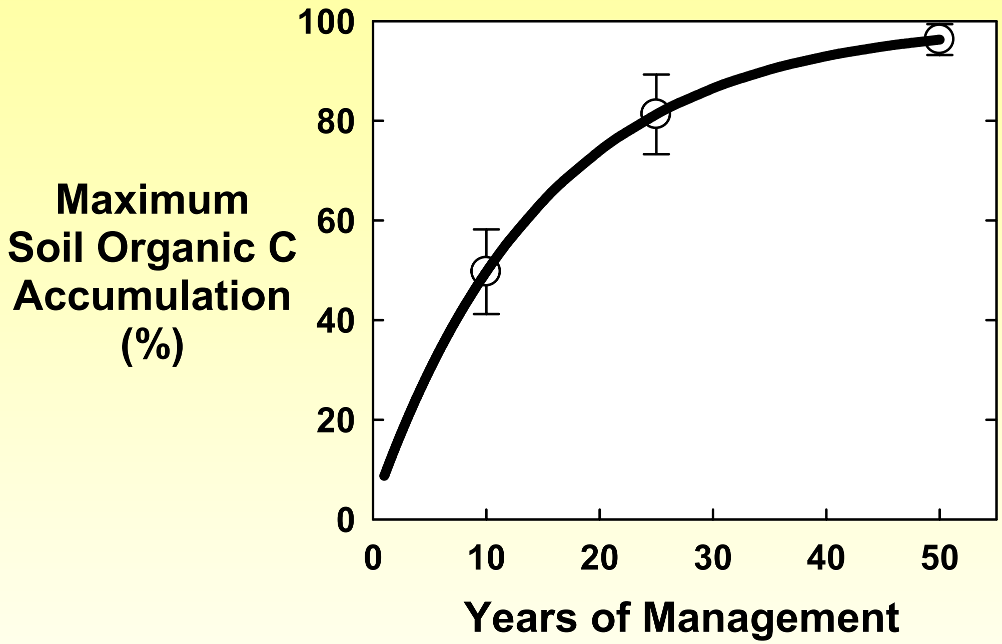
- **Utilization of ligno-cellulosic plant materials by ruminants**
- **Manure deposition directly on land**
- **Weeds can be managed with management rather than chemicals**

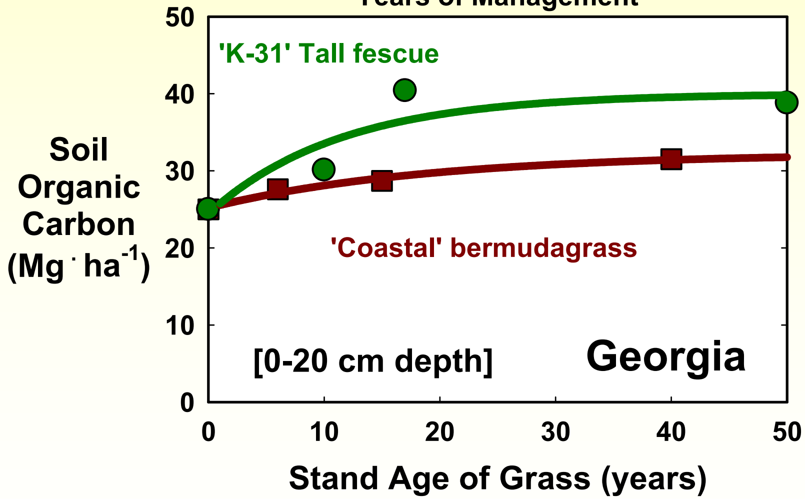
Franzluebbers and Stuedemann (2008)
Soil Sci. Soc. Am. J. 72:613-625

Soil Carbon Sequestration

Influence of pasture establishment





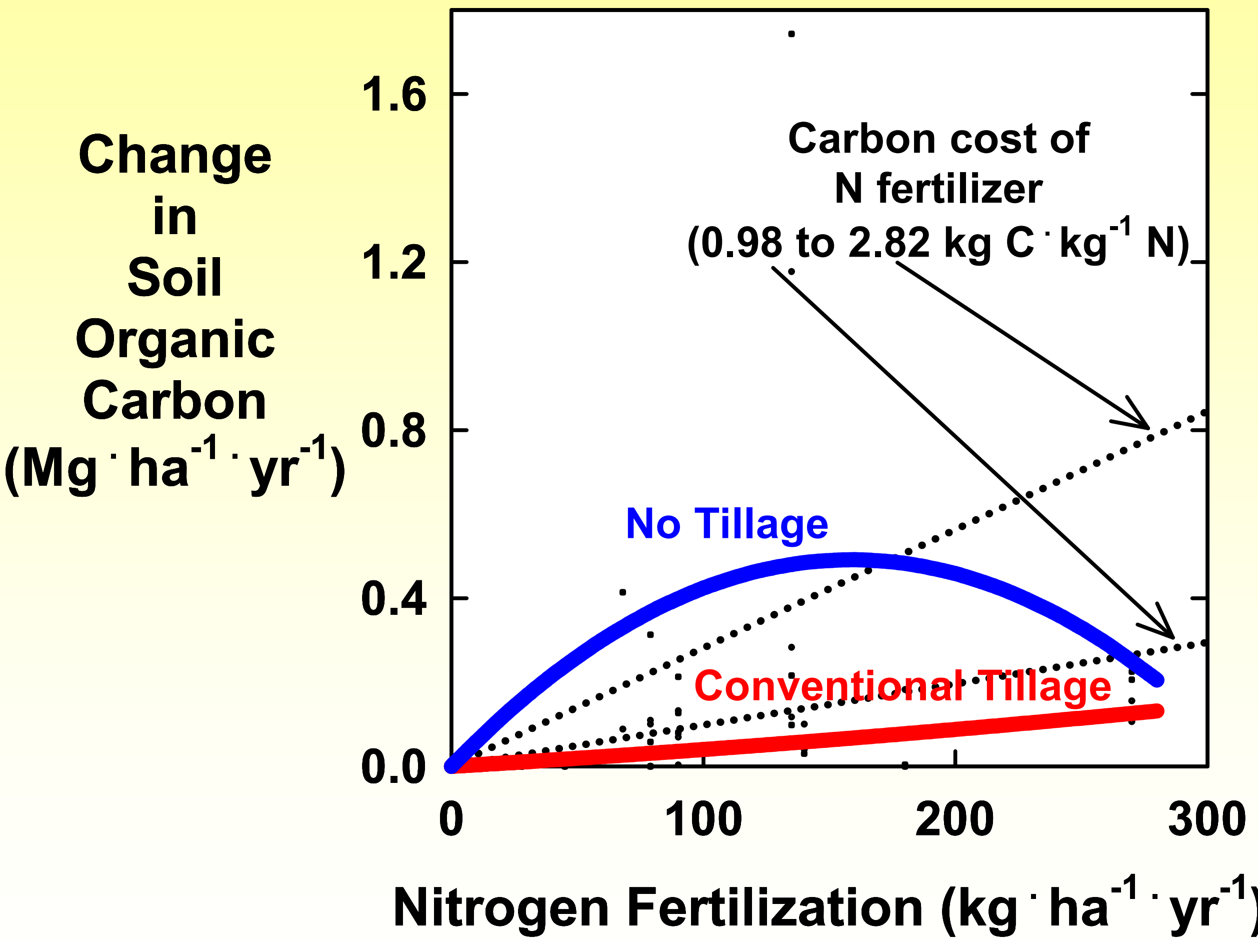


SOC ($Mg\ ha^{-1}\ yr^{-1}$)	10 yrs	25 yrs	50 yrs
Hayed BG (GA)	0.29	0.21	0.13
Grazed BG (TX)	0.50	0.33	0.19
Grazed TF (GA)	0.91	0.55	0.31

Data from Wright et al. (2004) Soil Biol. Biochem. 36:1809-1816
and Franzluebbers et al. (2000) Soil Biol. Biochem. 32:469-478

Soil Carbon Sequestration

Nitrogen fertilization effect



Therefore, soil carbon sequestration needs to be evaluated with a system-wide approach that includes all costs and benefits

For those of us working on greenhouse gas issues, this provides us with a formidable challenge

1 kg N_2O-N ha^{-1} = 127 kg C ha^{-1}

Franzluebbers (2005) Soil Tillage Res. 83:120-147

Nitrous Oxide Emission

Review of recent research

Tillage effects on N_2O emission from soils under corn and soybeans in eastern Canada, *Gregorich, Rochette, St-Georges, McKim, Chan*

Nitrous oxide and carbon dioxide emissions from monoculture and rotational **cropping** of corn, soybean and winter wheat, *Drury, Yang, Reynolds, McLaughlin*

Effect of **fertilizer nitrogen** management on N_2O emissions in commercial corn fields, *Zebarth, Rochette, Burton, Price*

Nitrous oxide, carbon dioxide and methane emissions from **irrigated** cropping systems as influenced by legumes, manure and fertilizer, *Ellert, Janzen*

Spring thaw and growing season N_2O emissions from a field planted with edible peas and a cover crop, *Pattey, Blackburn, Strachan, Desjardins, Dow*

Total of 12 papers in a special Issue “N2O Emissions from Agricultural Soils in Canada”
Can. J. Soil Sci. Volume 88, No. 2, April 2008

Nitrous Oxide Emission

Influence of cropping

Emission (kg N_2O-N ha^{-1})

Crop rotation	Crop		
	Corn	Soybean	Wheat
Monoculture	2.62 ± 1.82	0.84 ± 0.52	0.51 ± 0.15
Corn/soybean	1.34 ± 0.52	0.70 ± 0.43	–
Corn/soybean/wheat	1.64 ± 0.76	0.73 ± 0.24	0.72 ± 0.33

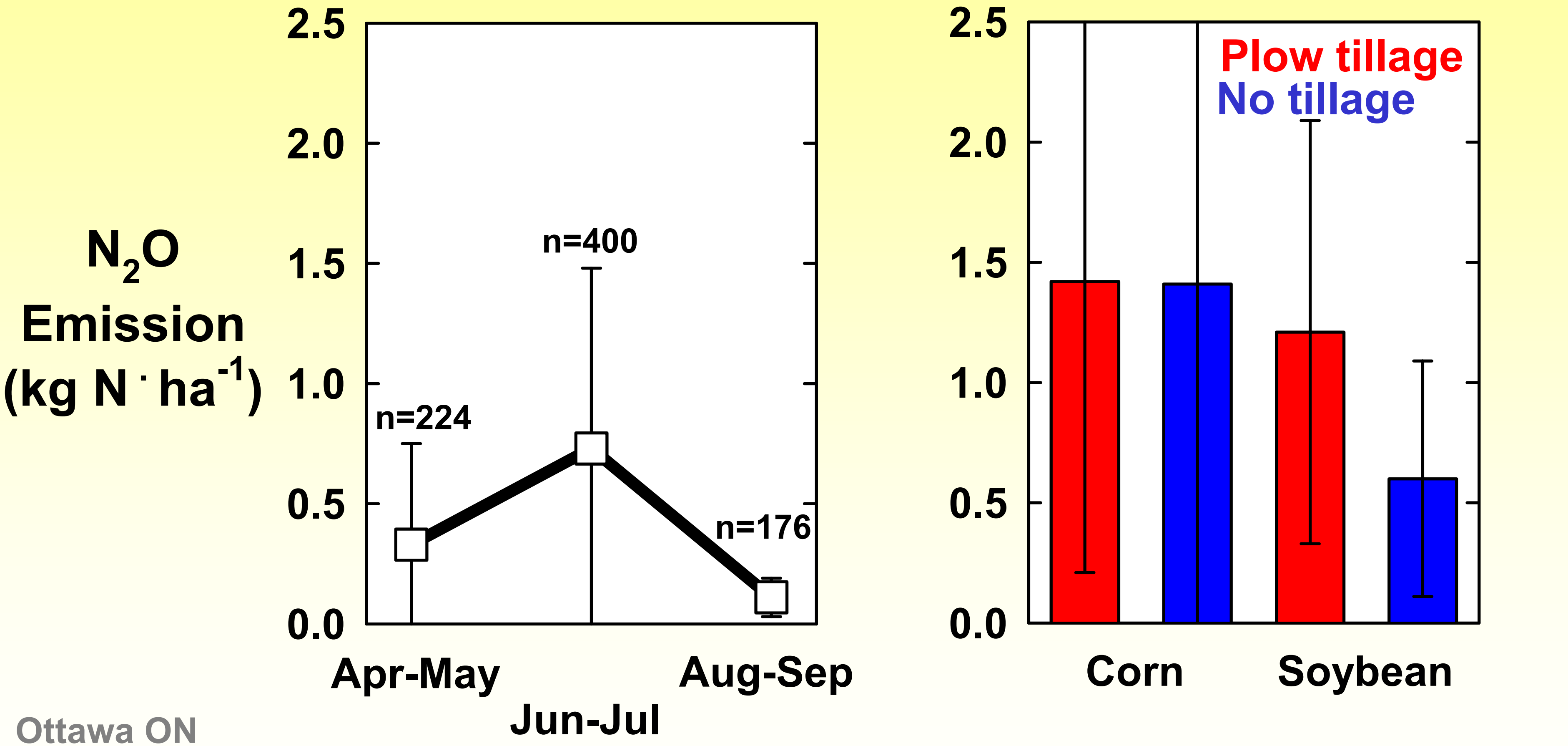
Importance of (1) N fertilizer rate, (2) type and amount of residue from previous crop, and (3) residual N.

Woodslee ON
Brookston clay loam
In Years 2, 3, and 4
Fertilizer – 170 kg N/ha corn,
83 kg N/ha wheat, none for soybean

Drury et al. (2008) Can. J. Soil Sci. 88:163-174

Nitrous Oxide Emission

Influence of season, crop, and tillage



Ottawa ON
Loam soil
Corn-wheat-soybean rotation
In Years 9, 10, and 11
Fertilizer (112 kg N/ha) corn only

Importance of soil nitrate from fertilizer

Gregorich et al. (2008) Can. J. Soil Sci. 88:153-161

Nitrous Oxide Emission

Influence of residues, tillage, and fertilizer

Emission (kg N_2O-N ha^{-1})

Condition	Annual crops / fall incorporation	Annual crops / not incorporated	Perennial crops / not incorporated
Winter/spring (n= 6-10)	2.41 ± 1.79	1.19 ± 0.79	0.29 ± 0.39

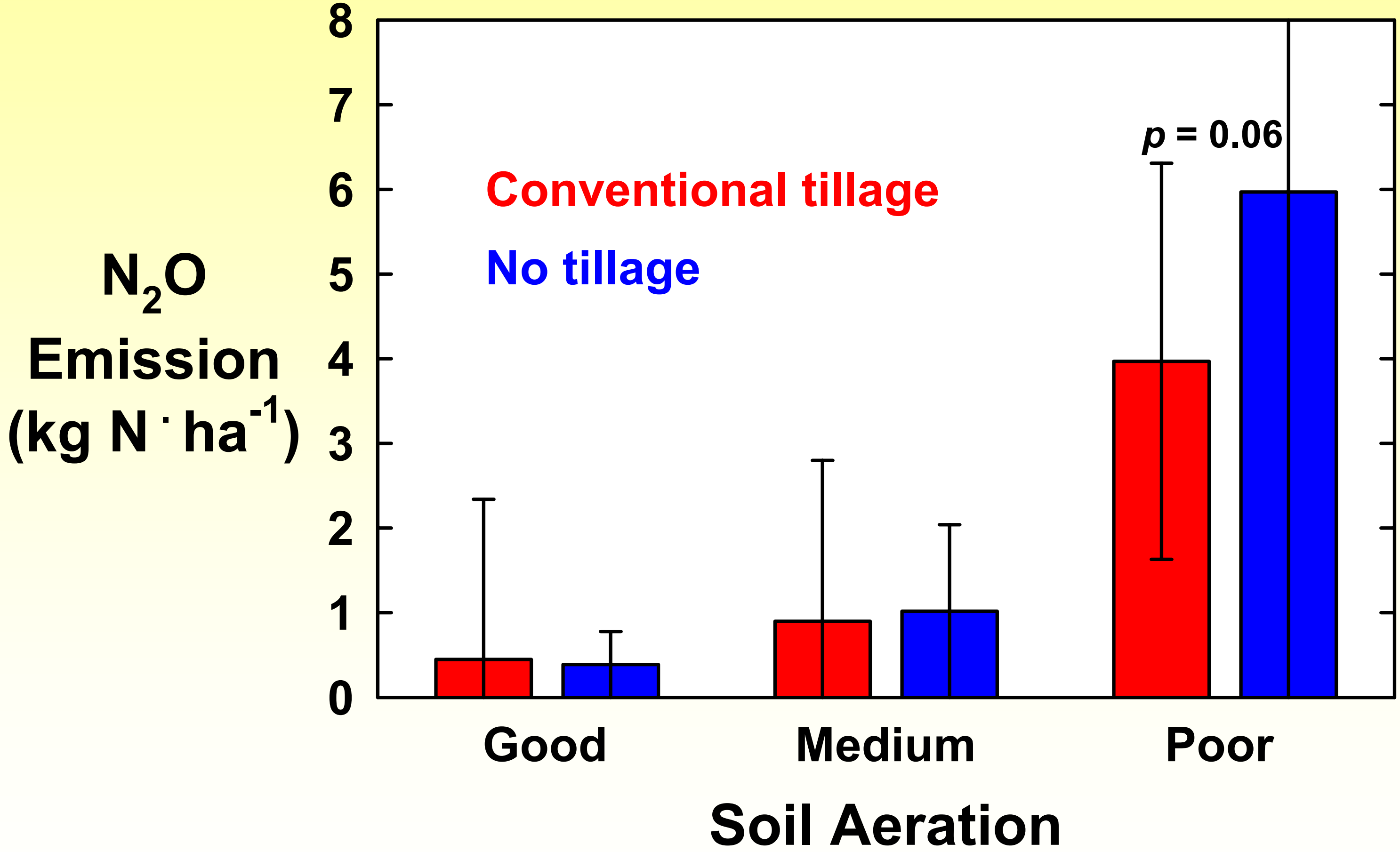
Condition	Moldboard plow	No tillage
Tillage (n=15)	1.60 ± 3.16	1.96 ± 4.66

Condition	− N fertilizer	+ N fertilizer
Annual crops (n=14-57)	1.53 ± 1.00	2.82 ± 2.78
Perennial crops (n=6-9)	0.16 ± 0.21	0.62 ± 1.10

Gregorich et al. (2005) Soil Till. Res. 83:53-72

Nitrous Oxide Emission

Interaction of tillage with soil type

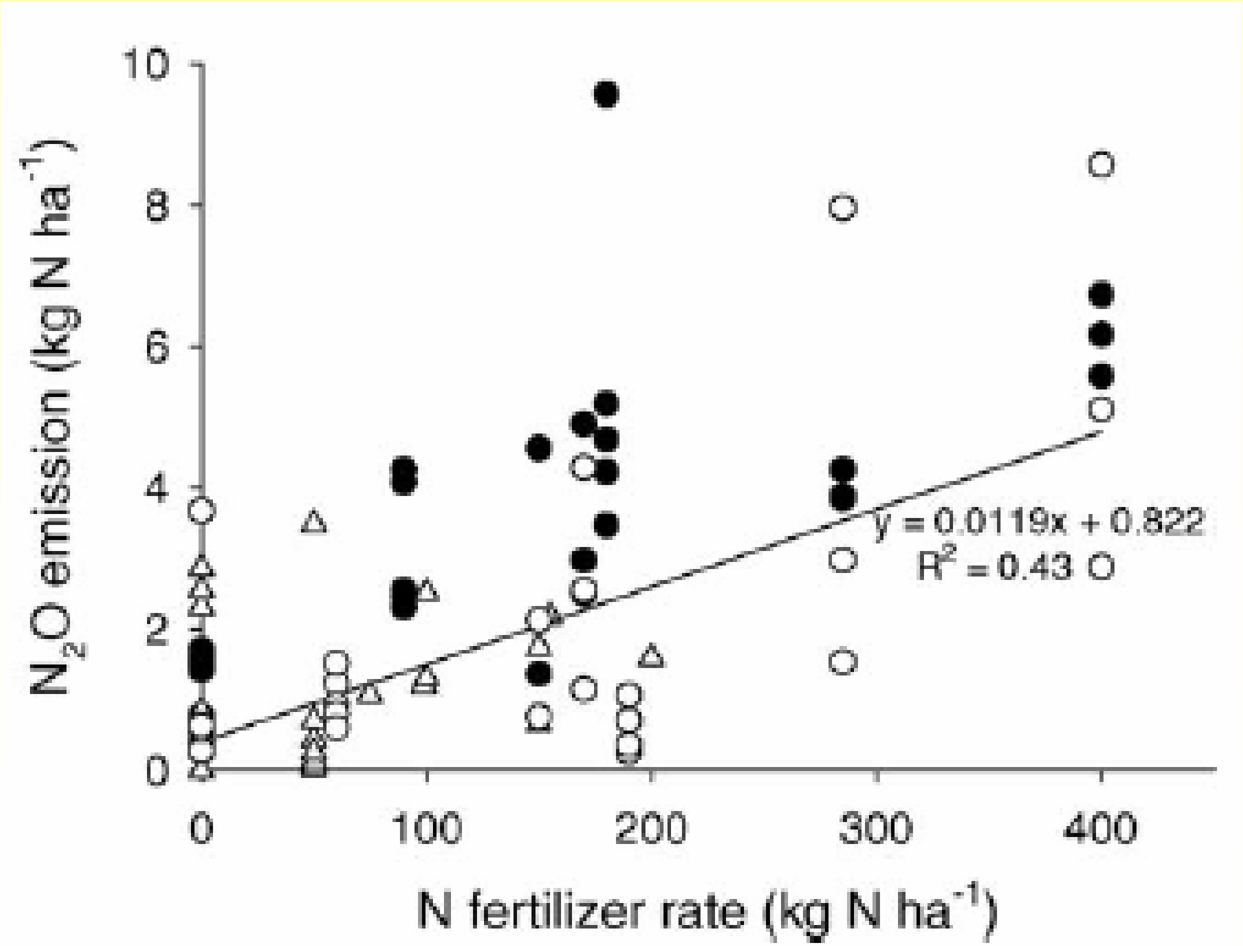


45 site-years of data reviewed
Brazil, Canada, France, Japan,
New Zealand, United Kingdom, USA

Rochette (2008) Soil Till. Res. 101:97-100

Nitrous Oxide Emission

Influence of N fertilizer



1.19% of applied fertilizer N emitted as N_2O

Compared favorably with the IPCC coefficient of 1.25%

Note the high variation in data despite the close comparison

Gregorich et al. (2005) Soil Till. Res. 83:53-72

Soil Carbon Sequestration

Influence of crop residue removal

At end of 7 years

Response 0-20-cm depth	Initially	Silage Crop Removal 0.5 yr^{-1}		1-2 yr^{-1}
Bulk density ($Mg\ m^{-3}$)	1.43	1.37	ns	1.39
Macroaggregate stability ($g\ g^{-1}$)	0.74	0.87	*	0.81
Soil organic C ($mg\ g^{-1}$)	11.7	14.3	*	12.5

On-farm research
North Carolina Piedmont
Corn silage each year vs corn silage less often

Franzluebbers and Brock (2007)
Soil Till. Res. 93:126-137

Soil Responses to Crop Residue Removal

- ✓ Reduced water infiltration, especially with >50% removal
- ✓ Increased soil erosion, most likely with >50% removal
- ✓ Reduced soil organic C and N storage (dependent upon soils, climate, etc.)
  - Soil organic matter is a key component that controls many other soil properties
- ✓ Reduced water storage and increased surface soil temperature
- ✓ Increased soil strength
- ✓ Reduced soil aggregation
- ✓ Reduced soil biological activity

Soil Carbon Sequestration

Summary

Soil organic carbon can be sequestered with adoption of conservation agricultural practices

- ✓ Enhanced soil fertility and soil quality
- ✓ Mitigation of greenhouse gas emissions
- ✓ Soil surface change is most notable
- ✓ Long-term changes are most scientifically defensible

Soil Carbon Sequestration

Acknowledgements

Funding

Agricultural Research Service (ARS)
US-Department of Energy
Madison County Cattleman's Association
USDA-National Research Initiative – Soil Processes
Cotton Incorporated
Georgia Commodity Commission for Corn
The Organic Center
ARS GRACEnet team